1906
K63

KIRK

Tests on Bond between
Concrete and Steel

Civil Engineering
BS
1906

UNIVERSITY
OF
ILL. LIBRARY

UNIVERSITY OF ILLINOIS
LIBRARY

Class 1906
Book K63
Volume

Je 06-10M

TESTS ON BOND

BETWEEN

CONCRETE AND STEEL

BY

TODD KIRK

THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

PRESENTED JUNE 1906

Digitized by the Internet Archive
in 2013

http://archive.org/details/testsonbondbetwe00kirk

1906
K63

U N I V E R S I T Y   O F   I L L I N O I S

May 29, 1906

This is to certify that the following thesis prepared under the direction of Professor A. N. Talbot, Head of the Department of Theoretical and Applied Mechanics, by

TODD KIRK

entitled TESTS OF BOND BETWEEN CONCRETE AND STEEL

is hereby approved by me as fulfilling this part of the requirements for the Degree of Bachelor of Science in Civil Engineering.

Ira O. Baker.

Head of Department of Civil Engineering

88079

BOND BETWEEN CONCRETE AND STEEL.

Introduction.

That the bond between concrete and steel consists of real adhesion, frictional resistance and shear, is the hypothesis taken in this discussion by the author. These are the terms generally used to denote the elements in the make up of the total bond. Adhesion may be termed the molecular attraction between the concrete and steel. Very little progress has been made in determining the amount of this attraction, it being difficult to experimentally divide the total bond into the three components.

That the frictional resistance is the principal item has been surely proven by experiments made in the past by such men as Marsh, De Joly, M. Feret and M. Considere. Very little shear was developed with the plain bars used in these tests. In tests where patented bars are used the shear caused by the concrete entering the projections of the bar is great but this cannot be called pure bond and is therefore termed mechanical bond.

Marsh says that the property generally referred to as "adhesion of the concrete to the steel" is probably due only in a slight degree to any direct adhesion, and would perhaps be better defined as frictional resistance due to the setting of the concrete, the outer portions of which harden first

causing the concrete around the bar to become compressed and so grasp the bar tightly.

In a thesis on this subject presented at the University of Minnesota in 1905 the same hypothesis was taken as is taken in this discussion and some conclusions were arrived at that agree in general with the writer's ideas; viz:

(1) With plain bars from 40 to 80 per cent. of the bond is due to frictional resistance between the concrete and steel.

(2) Shape of the bars has an effect on the total bond.

(3) Shear and real adhesion constitute a part of the total bond.

(4) The bond with patented bars is due largely to shear of the concrete.

That only a small part of the bond is real adhesion is clearly shown in several ways; viz., metal moulds drop away from the concrete with a slight tap on the side, and a piece of steel laid flat on the mixture and allowed to stay undisturbed until the concrete has set is also easily pulled off. If the steel is pressed down into the mass so that more than one side is covered the grip or pressure of the concrete will cause more difficulty in removing the steel. This is in accordance with Marsh's conclusion.

M. De Joly says that generally a very thin layer of the concrete remains on the reinforcement after being pulled out, this showing that probably the failure is due to the shearing of the concrete itself. If this be true, then the adhesion must be greater than the shearing strength and it may be true

that the failure is due more to the shearing of the concrete than the sliding of the rod. Marsh says that this is a fact that is becoming quite widely recognized.

The tests described in this thesis were made at two different times and of different materials. Most of those made in 1905 are not satisfactory nor of much value. A few, those set in water and those using the tool steel, are reliable.

DESCRIPTION OF MATERIALS.

The materials used in this thesis were such as are used in standard practice and in other tests on reinforced concrete in the laboratory.

Materials used in making the specimens in 1905.

STONE: Kankakee limestone ordered screened through a 1 inch screen and to be retained on a 1/4 inch screen. Per cent. of voids 45.

SAND: Purchased from the Garden City Sand Co., Chicago. It was clean, sharp, and screened through a 1/4-inch mesh screen before using. It weighed 103 lbs. per cu. ft. loose, and contained 28-30 per cent. voids.

STEEL: Two kinds of steel were used. Rods 1/2 inch in diameter from the Carnegie Steel Co. Elastic limit 40,000 lbs. per sq. in. and 3/4 inch rods from the Crescent Steel Co., elastic limit 60,000 lbs. per sq. in. Tests were made and it was found that the 1/2 inch rods had an average elastic limit of 33,760 lbs. per sq. in., ultimate strength 52,480

lbs. per sq. in., and 31 per cent. elongation. The tool steel (elastic limit 60,000 lbs per sq. in.) had a smooth glazed surface, average elastic limit 52,900 lbs. per sq. in., ultimate strength 84,820 lbs. per sq. in., 24.7 per cent. elongation.

Materials used in making the specimens in 1906.

STONE: The broken stone used was Kankakee limestone ordered screened through a 1 inch screen and over a 1/4-inch screen. It contained about 50 per cent. of voids.

SAND: The sand was from the Wabash river near Attica, Ind. It was not very sharp or angular but clean and of good quality. Analysis of sand:

Fineness.

Seive No.	Percent. passing
4	100
10	73
20	36
50	12
74	5
100	2

Percent. of Voids.

mean=28

No.	wt. Sand-gms	wt. Water-gms	wt. Mixed-gms	Percent Voids
1	1070	655	1240	26
2	1120	655	1315	30
3	1075	655	1265	29
4	1080	655	1255	27
5	1010	655	1190	28

CEMENT: The cement used was a mixture of several standard brands reground after mixing. Tensile tests of briquettes were made, viz., neat cement and a 1 to 3 mixture of cement and sand. The tests of the neat briquettes were not satisfactory, the testing machine being out of order. All of them broke in the grips of the machine. The 1 to 3 tests are given below.

Age: 7 days.

No.	Tensile strength lbs. per sq. in.
1	109
2	113
3	109
4	117
5	116
6	120

mean=114 lbs. per sq. in.

STEEL: It was decided to use plain bars entirely in making the specimens for this thesis. When patented bars are used no account of the frictional resistance can be determined, while in all cases with the plain bars this element of the bond proves itself to be the principal item.

The steel used was of four kinds; 1/2 in. and 5/8 in. plain round rods, 1 in. and 1/2 in. smooth steel shafting, 1-1/2 x 3/16 flat bars, and Johnson corrugated bars. The average steel tests are given below.

Type of rod	Size	Elastic limit	Ultimate strength	Percent of elongation
Plain	1/2	7650	11500	31
"	5/8	11500	17850	31
Smooth	1	27000	70400	10
"	1/2	17500	18300	10
Flat	1-1/2x3/16	16000	19500	20.2

MOULDS: In making the specimens 20 moulds were used, 12 of which were 6 inches long and 8 were 12 inches long. All were 6 inches in diameter. They were made of galvanized iron in one piece split down vertically and with a 1/16 inch shoulder to prevent slipping. Iron straps were bolted around the moulds to hold them to the right diameter—6 inches.

METHOD OF MAKING AND TESTING SPECIMENS.

All the specimens made in 1905 were of one proportion of concrete, viz., 1-3-6. The ingredients were measured by loose volume. This was the proportion most generally used in the making of reinforced concrete beams in the laboratory at that time. Enough water was used to give a medium wet mixture so that when thoroughly tamped the water flushed out at the top.

The specimens this year, 1906, were made in the same manner but different proportions were used, viz., 1-3-5 1/2 and 1-2-4. The sand and cement were thoroughly mixed, and the stone then dumped on, and the whole mass mixed, the stone having been sprinkled with water. Water was then added and the whole mass thoroughly turned with shovels, until the concrete was of a uniform color and consistency.

The concrete was then placed in the moulds in small amounts and thoroughly rammed with an iron bolt until the whole mass was in a quaking condition and some little water flushed to the top. To prevent rapid evaporation the specimens were sprinkled with water for several days after making.

Two imbedded lengths were used, viz., a length of 6 inches which was designed to keep the load under the elastic limit of the bar and a length of 12 inches which was designed to make the load run about to the elastic limit of the bar.

The testing was all done on a Riehle 100,000 lbs., testing machine, using the slowest speed, about 0.1 inch per min.

In testing the specimens the free end of the rod was fastened to the clamps of the upper fixed head, the rod running down through the movable head. The load was transmitted from the movable head to a cast iron plate which transmitted the load to the concrete through a plaster of paris cushion. This plaster was used to get an even bearing on the concrete and was allowed to set under a small load of about 250 lbs. When the plaster of paris had set the movable head was run down applying the load slowly until the bond broke and the rod slipped.

When the elastic limit of the bar was reached before the bond broke the load was recorded and then run on up to the maximum load. When the rod had slipped about a 1/4 inch the load was recorded as the amount of the running friction.

DISCUSSION OF RESULTS.

Results for Tests in 1905.

Most of the results obtained from the tests made in 1905 are unsatisfactory on account of an accident which occurred in the laboratory while the specimens were maturing. Most of them were completely spoiled while some others, which, to all appearances were uninjured, did not come up to expectations when tested. Those specimens which were allowed to set in water and the ones with the 3/4 in. tool steel were not disturbed at all, having been removed from the testing room before the accident occurred. The consistency of the results from the 1/2 inch plain rods wrapped with oiled paper tends to show that these probably were not disturbed.

From table III. a comparison can be made between the results of specimens set in water and those set in air. It is seen that the average values of those set in water is lower than the highest value of the ones set in air. This comparison is not reliable in this case as only two of the specimens set in air appear to be at all in accordance with the estimated values. The value of these should not be less than 350 lbs. per sq. in.

The values of the 3/4 inch tool steel are fairly consistant and show that the bond per sq. in. decreases with the smoothness of the surface of the metal.

Results from Tests in 1906.

The results of this year's tests are very satisfactory and are free from any wide variation. Comparisons of all the results have been made in table II.

A comparison between the long and short imbedded lengths for the 1/2 in. rods shows that the values for both in lbs. per sq. in. are nearly alike, while for the 5/8 in. rods there is quite a variation.

It is seen that with the 1-3-5 1/2 mixture the value of the short imbedded length, 5/8 in. rod, is 47 lbs. per sq. in. less than that of the longer imbedded rod of the same size, and for the 1-2-4 mixture the shorter length is 43 lbs. per sq. in. more than the value for the longer.

As far as can be seen there is no good reason for this variation unless the condition of the rods entered into the results. This is probably the cause of the variation, some of the rods being more rusted or rough than the others. Very probably the short rods were smoother and some oil may have fallen upon them.

No accurate division of the total bond into its constituents can be determined. With the plain bars the value of the running friction varies from 54 percent. to 72 percent. of the total bond. Contrary to expectations, the value of the running friction is, with one exception, greater with the leaner mixtures than with the richer ones. This may be accounted for by allowing that the shear and real adhesion amount

to more in the leaner mixtures. The running friction, except with the tool steel rods and flat steel bars, is fairly uniform irrespective of the size of the rod. The running friction does not become uniform until the rod has slipped about 1/4 in. this allowing the particles of concrete adhering to the steel and filling the small indentations of the rod to be sheared off. Before these particles were sheared off the load averaged 80 to 90 percent. of the maximum load. Probably only about 5 percent. of the total bond is real adhesion. As shown by table III. the values for the flat 1-1/2 in. x 3/16 in. rods are considerably lower than for the round rods. The reason for this is that the concrete probably did not adhere closely to the metal around the sharp angles. In expanding or contracting while setting the concrete tends to break away from the sharp re-entrant angles and hence gives lower values than with round rods. The concrete split out from the center and down the side in the case of the Johnson bars and when the rods were pulled out some concrete remained between the projections of the rod.

COMPRESSION TESTS.

After having pulled the rods out a number of the concrete blocks were tested in compression. Judging from other compression tests made in the laboratory the effect of having been stressed from 1000 lbs. to 12,000 lbs., and having a vertical hole of from .20 sq. in. to .785 sq. in. in the middle, was hardly noticeable.

CONCLUSIONS.

(1) The bond with patented bars, as the Johnson bar, is due largely to the shearing of the concrete as shown by concrete remaining between the projections of the rod.

(2) With plain rods 50 percent. to 75 percent. of the total bond is due to the running friction between the concrete and steel.

(3) The bond with rods having a rough and rusted surface is greater than with rods having a smooth surface. The same may be said of the running friction.

(4) The shape of the rod has quite an effect on the bond.

(5) The bond is greater with rich mixtures than with lean ones.

(6) Shear and adhesion form a part of the total bond.

(7) The safe allowable working stress for bond of plain rods in ordinary condition should not exceed 125 to 150 lbs. per sq. in. of surface exposed to concrete.

(8) There is very little difference in the bond per sq. in. for long and short imbedded lengths for the same type of rods and mixture.

Table I.

No. of specimen	Type of rod	Size ins.	Proportion of ingredients of concrete	age of con. days.	Imbeded length ins.	Area of exposed surface sq.ins.	Maximum load lbs.	Bond per sq in net surface	Running Friction Max. load	Running friction lbs per sq.in.net sur.	Unit stress in steel lbs per sq.in.net sect.	Remarks.
1	Plain	½"	1-3-5½	60	6	9.42	3900	360	1850	196	17000	Rod slipped.
2	"	"	"	"	"	"	3360	356	1900	201	16800	" "
3	"	"	"	"	"	"	3510	372	1950	207	16550	" "
4	"	"	"	"	"	"	3550	377	2000	212	18200	" "
5	"	"	"	"	"	"	3640	386	2150	228	18200	" "
6	"	"	"	"	"	"	3530	375	2050	218	17650	" "
7	Plain	⅝"	"	"	"	11.77	4300	365	3000	257	19000	" "
8	"	"	"	"	"	"	4195	358	2600	221	13650	" "
9	"	"	"	"	"	"	4250	361	2500	212	13750	" "
10	"	"	"	"	"	"	4150	352	2650	~~234~~ 225	13520	" "
11	"	"	"	"	"	"	4075	346	2500	212	13300	" "
12	"	"	"	"	"	"	4050	342	2950	251	13200	" "
13	Plain	½	1-2-4	"	12	18.84	8200	436	5500	292	41000	Elastic Limit of steel, 7580, reached before max. load.
14	"	"	"	"	"	"	6820	362	5200	276	39100	Rod slipped.
15	"	⅝"	"	"	"	23.54	11200	476	7500	318	56000	E.L. of steel reached 10290 before max. load.

13

No of Specimen	Type of rod.	Size ins.	Proportion of ingredients of concrete.	Age of con., days.	Imbeded length ins.	Area of exposed surface sq. ins.	Maximum load lbs.	Bond per sq. in net surface	Running Friction Max. load.	Runn. Frict. lbs. per sq. in net surface	Unit stress in steel lbs per sq. in net sect.	Remarks.
16	Plain	$\frac{1}{2}$"	1-3-5½	60	12	18.84	7130	378	5400	~~294~~ 286	~~35650~~ 36400	Rod slipped.
17	"	"	"	"	"	"	7475	397	5300	281	32500 38100	E.L. of steel = 7150.**
18	"	"	"	"	"	"	6500.	345	4500	239	32500 33100	Rod slipped.
19	"	$\frac{5}{8}$	"	"	"	23.54	10 000	425	5500	254	32700	" "
20	"	"	"	"	"	"	9 500	~~400~~ 404	6000	255	30950	" "
21	"	"	"	"	"	"	8875	377	5000	212	28500	" "
22	Steel shafting	1	"	"	6	18.84	2700	143	1500	~~82~~ 80	~~3050~~ 3440	" "
23	Cold Rolled "Shafting"	"	"	"	"	"	2200	118	1000	53	2490 2500	" "
24	" "	"	"	"	"	"	2810	150	1270	~~70~~ 67	3150	" "
25	" "	$\frac{1}{2}$	"	"	"	9.92	1425	~~161~~ 151	550	~~59~~ 58	7120	" "
26	" "	"	"	"	"	"	1610	170	450	48	8050 8220	" "
27	" "	"	"	"	"	"	1395	147	400	43	6970 7130	" "
28	Plain flat.	$1\frac{1}{2} \times \frac{3}{16}$	"	"	"	20.25	2260	111	1490	~~70~~ 71	8050	" "
29	" " "	"	"	"	"	"	2550	126	1700	83	9070	" "
30	" " "	"	"	"	"	"	2800	138	2000	98	9960	" "
31	Johnson	$\frac{1}{4}$	"	"	6	6.0	10750	1791	0	0		Concrete split.

No. of Specimen	Type of rod	Size of ins	Proportion of ingredients of concrete	Age of con. days	Imbeded length ins.	Area of exposed surface sq. ins.	Maximum load. lbs.	Bond per sq. in. net surface	Running Frict. Max load.	Runn. Frict. lbs. per sq. in. net surface	Unit Stress in steel lbs per sq in net sect.	Remarks.
32	Johnson	$\frac{1}{2}$	1-3-5$\frac{1}{2}$	60	6	12.0	12110	1009.	0	0		concrete split.
33	Plain	$\frac{1}{2}$	"	"	"	9.42	2350	250	1280	136	12,000 ~~11750~~	rod slipped.
34	"	$\frac{5}{8}$	1-2-4	"	"	11.77	5580	475	5400	289	18200	" "
35	"	"	1-2-4	"	"	11.77	5510	468	3390	288	18000	" "
36	"	"	"	"	"	"	5260	447 ~~470~~	3600	306	17150	" "
37	"	"	"	"	"	"	5530	471 ~~398~~	3550	302	18000	" "
38	"	$\frac{1}{2}$	"	"	12	18.84	7500	398	4500	239	24400 ~~37500~~	" "
39	"	"	"	"	"	"	7900	418	4730	251	25700 ~~39500~~	" "
40	"	$\frac{5}{8}$	"	"	"	23.54	9090	384 ~~387~~	4740	202	29450	" "
41	"	"	"	"	"	"	9000	382	4000	170	29350	" "
42	"	$\frac{1}{2}$	"	"	6	9.42	4000	425	2470	263	[illegible] ~~20000~~	" "
43	"	"	"	"	"	"	4490	477	2600	276	22900 ~~22450~~	" "
44	"	"	"	"	"	"	4040	428	2400	254	[illegible] ~~20200~~	" "
45	"	"	"	"	"	"	3840	408	1900	202	[illegible] ~~19200~~	" "
46	"	"	"	"	"	"	3650	388	1700	181	[illegible] ~~15250~~	" "
47	"	"	"	"	"	"	3340	355	1740	184	[illegible] ~~16700~~	" "

Table II.

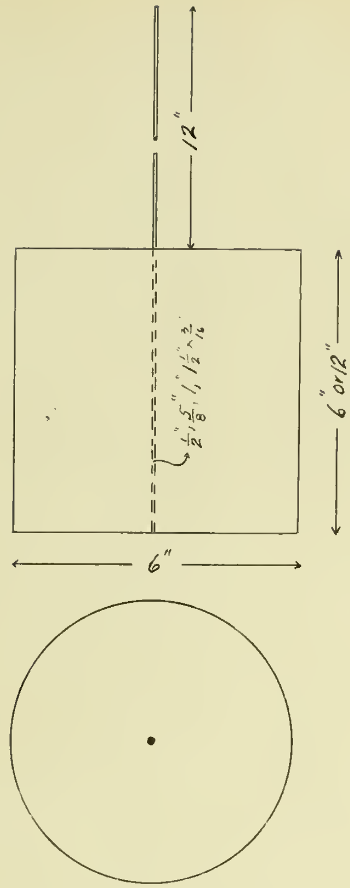
Number.	Type of rod	Size ins.	Prop. of ingredients of con.	Age days.	Imbeded length ins.	Area of exposed surface sq. ins.	Maximum load lb.	Bond per sq. in net surface	Running Frict. Max. load.	Runn. Frict. lbs per sq. in. net surface	o/o Friction to total bond.	o/o of increase in strength of 1-2-4 over 1-3-5½	Remarks.
6	Plain	½	1-3-5½	60	6	9.42	3998	372	1983	210	57.0		
6	"	"	1-2-4	"	"	"	3893	412	2135	227	55.2	10.5	
6	"	⅝	1-3-5½	"	"	11.77	4170	355	2700	~~229~~ 227	64.5		
4	"	"	1-2-4	"	"	"	5376	~~457~~ 465	3485	297	~~65.0~~ 64.0	12.9	
3	"	½	1-3-5½	"	12	18.84	7035	573	5066	268	72.0		
4	"	"	1-2-4	"	"	"	7605	~~406~~	4982	266	65.5	8.9	
3	"	⅝	1-3-5½	"	"	23.54	9458	402	5366	228	56.8		
3	"	"	1-2-4	"	"	"	9736	414	5248	223	54.0	3.0	
3	Steel shafting	1"	1-3-5½	"	6	18.84	2570	136	1256	67	49.2		
3	"	½	"	"	"	9.42	1476	157	466	50	31.8		
3	Plain 1½ x 3/16		"	"	"	20.25	2536	125	1713	84	67.1		
1	"	½	"	"	"	9.42	2350	250	1250	136	57.5		Poor Tamp.
1	Johnson		"	"	"		11 110						
1	"		"	"	"		10 750						

Table III.

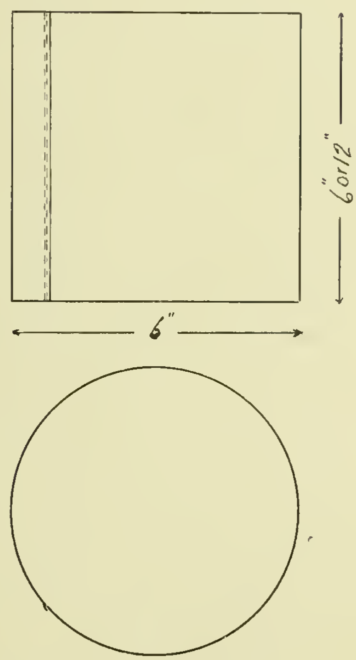
No. of specimen	Type of rod	Size ins.	Prop. of ingredients of concrete.	Age of con. days.	Imbeded length ins.	Area of exposed surface sq. ins.	Maximum load. lbs.	Bond per sq. in. net surface	Unit stress in steel lbs per sq. in. net sect.	Remarks and manner of failure.
1	Plain	$\frac{1}{2}$	1-3-6	60	6	9.42	2975	317	15150 ~~14875~~	Concrete split.
2	"	"	"	"	"	"	1705	181	8700 ~~8525~~	Rod slipped.
3	"	"	"	"	"	"	1195	127	[illegible] ~~5975~~	" "
4	"	"	"	"	"	"	3470	369	17700 ~~17350~~	" "
5	"	"	"	"	"	"	4910	522	25000 ~~24550~~	Concrete split.
6	"	"	"	"	"	"	2424	258	12400 ~~12120~~	Rod slipped.
7	"	"	"	"	"	"	1995	212	10200 ~~9975~~	" "
8	"	"	"	"	"	"	3040	323	15500 ~~15200~~	" "
9	"	"	"	"	"	"	2940	312	15000 ~~14700~~	" "
10	"	"	"	"	"	"	1000	106	5100 ~~5000~~	" "
11	"	"	"	"	"	"	1795	191	9160 ~~8975~~	" "
12	"	"	"	"	"	"	1524	162	7780 ~~7620~~	" "
13	"	"	"	"	"	"	2200	234	[illegible] ~~11000~~	
14	"	"	"	"	24	37.68	7575	201	[illegible] 37875	Concrete split and rod slipped. E.L. of steel: 7690
15	Oiled paper on rod "	"	"	"	6	9.42	565	60	[illegible] ~~2825~~	Rod slipped.
16	" "	"	"	"	6	"	527	56	[illegible] ~~2635~~	" "
17	Smooth	$\frac{3}{4}$	"	"	"	19.13	2181	153	[illegible] 5050	" " High steel.

Table III.

No of specimen	Type of rod	Size ins.	Prop. of ingredients of concrete	Age of con. days.	Imbeded length ins.	Area of exposed surface sq. ins.	Maximum load lbs	Bond per sq. in net surface	Unit stress in steel lbs per sq in net sect	Remarks and manner of failure.
18	Smooth Tool Steel	$\frac{3}{4}$	1-3-6	60	6	14.13	2060	147	~~4760~~ 4650	Rod slipped. High steel.
19	"	"	"	"	"	"	2180	154	~~5050~~ 4940	" " " "
20	"	"	"	"	"	"	1993	141	~~4610~~ 4[illegible]	" " " "
21	Plain	$\frac{1}{2}$	"	"	24	37.68	7130	190	~~35650~~ 3640[illegible]	Rod bent. Concrete gave away at 7000"
22	"	"	"	"	"					Rod bent. Con. broken.
23	Smooth	$\frac{3}{4}$	"	"	6	14.13	2540	180	~~5880~~ 5750	Rod slipped. High steel.
24	"	"	"	"	"	"	2200	156	~~5090~~ 49[illegible]	" " " "
25-29	"	"	"	"	"	"				No good. Rods loose and con. broken.
28	Oiled paper on rod Plain	$\frac{1}{2}$	"	"	"	9.42				" " " " "
29	" "	"	"	"	"	"	490	52	~~2450~~ 2500	Rod slipped.
30-34	"	$\frac{3}{4}$	"	"	"	"				No good. Rod bent + loose.
35	"	$\frac{1}{2}$	"	"	"	"	3050	324	~~15250~~ 15[illegible]	Rod slipped. Set in water. 60 days.
36	"	"	"	"	"	"	3220	342	~~16100~~ [illegible]	" "
37	"	"	"	"	"	"	3020	320	~~15100~~ [illegible]	" "
38	"	"	"	"	"	"	3120	332	~~15600~~ [illegible]	" "
39	"	"	"	"	"	"	3100	329	~~15500~~ 15[illegible]	" "
40	"	"	"	"	"	"	3190	339	~~15950~~ [illegible]	" "



Sketch of specimen.



Sketch of mould.

UNIVERSITY OF ILLINOIS-URBANA
3 0112 082195501